Indian J Phys. 76B (3), 251–254 (2002)

I J P B
an international journal

Geospot as a source of geothermal energy

Tushar K Das
Institute of Radio Physics & Electronics, 92, A P C Road, Kolkata-700 009, India
E-mail tusharkd@cucc.ernet.in

Received 6 February 2002, accepted 9 April 2002

Abstract The well known sources of geothermal energy that is responsible for affecting various geodynamical processes do not fulfil the exact requirement of energy needed for these purposes As an alternative to these tenable sources of energy, we have hypothesised the formation of a strong magnetic field zone, known as geospot, in the core-mantle boundary The magnetic loops and arches are formed in the *D''* region situated above the core-mantle boundary due to the growing or decaying geospots When a pair of bipolar regions approach one another, a current sheet is developed, in which magnetic reconnection process takes place, giving rise to the liberation of enormous amount of energy in the form of heat

Keywords Geospot, magnetic field, geothermal energy

PACS Nos. 91 35 Cb, 91 45 –c

1. Introduction

Geothermal energy which plays an important role in governing the different geodynamical processes, such as, plate motion, volcanism, hotspots, sialic thickening, convective plumes, mantle plumes, volcanic chain, mid-ocean ridge, island arc, polar wandering, is poorly understood. The tenable sources of energy that have been invoked from time to time [1–5] are (i) radioactive decay [6,7] of element like K^{40}, (ii) latent heat released due to the crystallisation of Fe-Ni on the surface of the inner core, (iii) gravitational energy released as a result of sinking of Fe to the centre, (iv) thermal energy released by planetesimal particles during accretion, (v) frictional heat developed because of migration of denser material downward.

Recently, Tassos [8] has proposed the idea of Exces Mass Stress (E.M.S.) as the driving force of geodynamic phenomena. The excess mass, the bulk matter generated at the core-mantle boundary, is the product of transformation of elementary particles into bulk matter, through electromagnetic confinement, laser clustering, and controlled nuclear fusions.

But none of these energy sources can adequately justify the energy requirement of the different geological phenomena which are rather discrete, cyclic and episodic in nature. As an alternative to the aforesaid sources of the internal energy of earth, we have hypothesised the formation of geospots at the core-mantle boundary [9–12] which play an active role in controlling the various geodynamical phenomena. This idea has been invoked on the basis of the proposition put forward by Sheridan [13] who observed that there exists a certain relationship of the dynamic processes like plate spreading and global sea level cycles with the geomagnetic field variation in a cyclic way.

2. Geospot—what and where

A geospot is a zone of strong magnetic field formed at the core-mantle boundary, having, probably, the temperature less than that of the surrounding medium. An isolated isothermal magnetic flux tube is detached from the toroidal field of earth due to some sort of perturbation and is carried to the core-mantle boundary by an ordered, large scale convective flow. This magnetic flux tube, which is dragged by the updraft convection, maintains its axis approximately vertical (Figure 1) and reaches at the core-mantle boundary where it undergoes some evolutionary changes to form a geospot.

In the core-mantle boundary, the iron permeates from the core into the lower mantle, whereas, the oxygen and to some extent, silicon and magnesium enter into the core from the mantle (Figure 2). The iron carries the 'frozen-in' magnetic field associated with it and deposits at the upper part of the core-mantle boundary. The sub-surface downdraft caused by O-Si-Mg is assumed to flow between the individual flux strands towards the geospot axis and to provide a confining force by exerting an aerodynamic drag on the strands, Futhermore, the presence of strong magnetic field in the geospot causes the convection to be inhibited through the region where the flux concentration takes place [14,15]. This results in the reduced heat flux and temperature in the geospot.

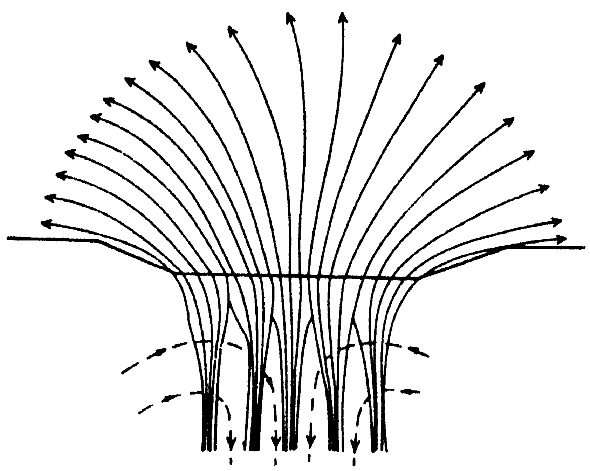

Figure 1. Geospot's magnetic field structure

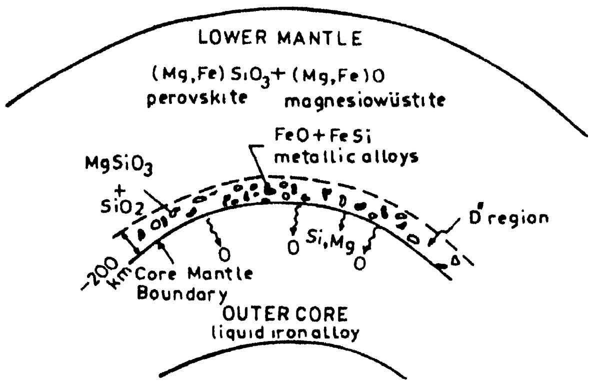

Figure 2. Earth's interior showing the core-mantle boundary and D'' region containing highly conducting and insulating alloys.

3. Energy release site and storage

Growth and decay of a geospot which has its associated magnetic field varying accordingly were treated in one of our earlier papers [9]. Here, we concentrate on the energy release site and its storage mechanism. The interface between D'' region and the mantle has been presumed to be the site for the liberation of energy which is convected to the mantle. The regions are characterised by a host of strong magnetic fields, concentrated in flux tubes that form loops and arches of different sizes in the D'' layer. The foot points of these loops are lying on the upper core D'' regions boundary. These loops are formed due to the variation of magnetic flux of the geospots which are emerging or decaying.

The region where the energy is released is surmounted with a magnetic loop as shown in Figure 3(a). As D'' region is heterogeneous in nature with assemblages of highly conducting as well as insulating alloys, resulting from chemical reactions at the core-mantle boundary and the percolation of iron into the mantle, we are prompted to consider the physical characteristics as illustrated in Figure 3(b).

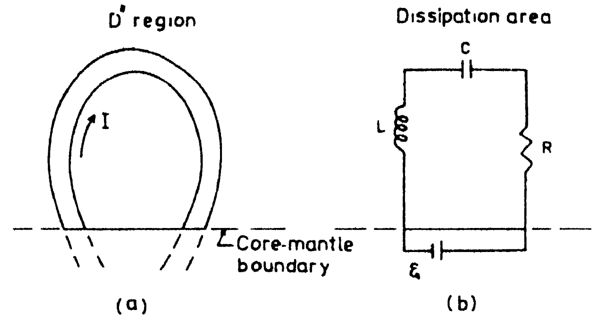

Figure 3. Electrodynamic circuit for remote energy storage

An electric current I is assumed to flow in the magnetic loop between the upper core-mantle boundary and the D'' region. An insulating layer in between two conducting layers gives rise to the effect of formation of a capacitor C, whereas, R and L give the total resistance and inductance respectively of the equivalent electrodynamic circuit.

It is assumed that an electric circuit transports energy from the upper core-mantle boundary to the upper most region of D'' layer from where the energy in the form of heat is convected to the mantle. This is the heat source necessary for mantle convection.

To examine the global aspect of this sort of storage mechanism, we have used the equation for the total current I of the electrical circuit shown in Figure 3 (b)

$$\frac{dI}{dt} \quad \frac{Q}{C}.$$

Here, E is the emf to the electrodynamic force generated in the cooler layers of D'' region where degree of ionisation is low enough so that sufficient neutral atoms are available to carry the positive ions across the magnetic field lines. According to the dynamo principle

$$= \int | \boldsymbol{v}_n \times \boldsymbol{B} | dx.$$

where $\boldsymbol{v}_n$ is the velocity of the neutral atoms.

Putting

$$Q = q \cdot CE \text{ and } I = \frac{dQ}{dt},$$

$$q = CE\left[1 - \frac{1}{2\beta}e^{-\alpha t}\left\{(\alpha+\beta)e^{\beta t} - (\alpha-\beta)e^{-\beta t}\right\}\right],$$

where $\alpha = \frac{R}{2L}$ and $\beta = \sqrt{\frac{R^2}{4L^2} - \frac{1}{LC}}$.

When R is very small (it is the characteristics of D'' region because of high conductivity), the equation simplifies to

$$q = CE + A_0 e^{-\alpha t}\sin(\omega_0 t + \epsilon),$$

where A_0 and ϵ are arbitrary constants.

Putting $q = 0$ and $I = 0$ at $t = 0$, the values are

$$\tan \epsilon = \frac{\omega_0}{\alpha},$$

$$A_0 = \frac{\sqrt{\omega_0^2 + \alpha^2}}{\omega_0} CE,$$

$$\omega_0^2 = \frac{1}{LC} - \frac{R^2}{4L^2}.$$

The current is

$$I = I_0 e^{-\alpha t}\sin\omega_0 t,$$

where $I_0 = \frac{\omega_0^2 + \alpha^2}{\omega_0} CE = \frac{E}{L\omega_0}$.

$$q = CE\left[1 - \frac{\sqrt{\omega_0^2 + \alpha^2}}{\omega_0} e^{-\alpha t}\sin(\omega_0 t + \epsilon)\right].$$

Average inductive energy over a half cycle

$$= \frac{2}{T_0}\int_0^{\frac{T_0}{2}} \frac{1}{2} LI^2 dt \cong \frac{1}{4} CE^2.$$

Average capacitive energy

$$= \frac{2}{T_0}\int_0^{\frac{T_0}{2}} \frac{q^2}{2} dt \cong \frac{1}{4} CE^2.$$

Hence, total energy $= \frac{1}{2} CE^2$.

During oscillations, the charge may become considerably greater than the final value CE, and consequently the potential difference between the plates may exceed E. This results in a breakdown of the dielectric between the plates, entailing destruction of the capacitor. So at the site where this happens in the D'' region, the medium becomes homogeneous.

4. Formation of current sheet and magnetic reconnection

According to Sweet [16] and later developed by Gold-Hoyle [17], a pair of bipolar regions (Figure 4) approach one another and merge together to form a neutral current sheet. In sketching these field lines it has been considered that the field strength increases with distance from the origin, so that

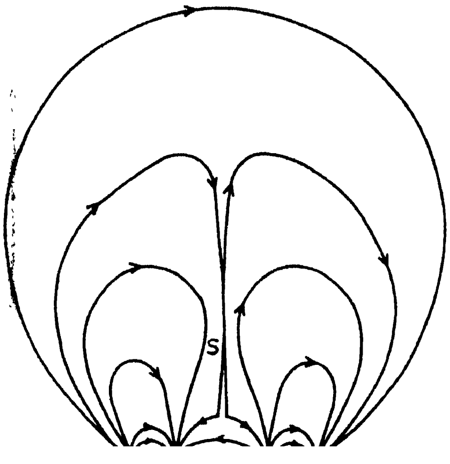

Figure 4. A pair (D1, D2) of bipolar regions approaching towards each other

the hyperbolae (Figure 5) are situated successively closer to one another. Any element of material experiences a resultant magnetic tension due to the outwardly curving field lines. It acts outwards from the origin and is exactly balanced by the magnetic pressure which acts inwards as the magnetic field becomes smaller and smaller if the origin is approached.

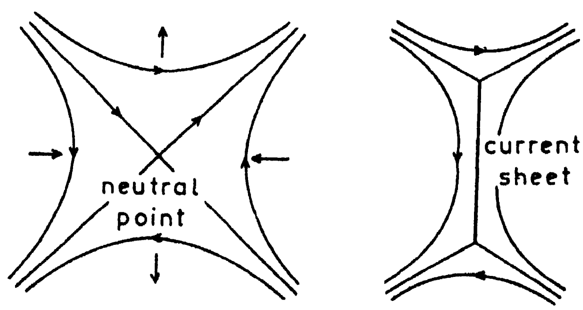

Figure 5. Formation of a current sheet

The major problem faced by any mechanism by which the stored magnetic energy is dissipated is the high conductivity of the material of D'' region, with associated long magnetic diffusion times and high magnetic Reynolds numbers, which necessitates the frozen-in field to move with the medium and so inhibits its motion. Since the diffusion time scale varies as the square of the characteristic length 'l' associated with changes in magnetic field, it is desirable that this length l should be as small as possible. The neutral sheet (Figure 5) satisfies this criterian. Such configuration can result in magnetic reconnection.

According to the Figure 6, the magnetic field component B_y reverses direction along the line $X = 0$. For the sake of simplicity, let us assume that the field geometry is independent of the coordinate Z (out of the paper).

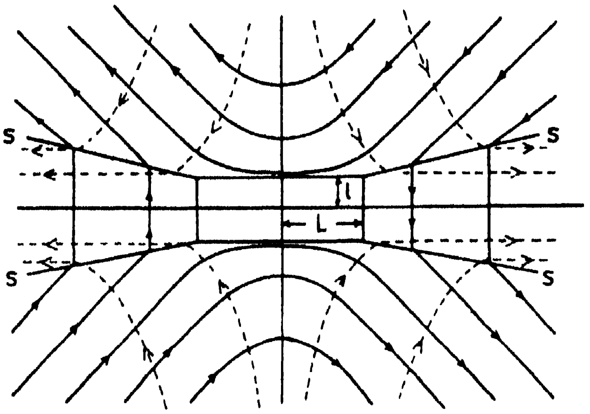

Figure 6. Magnetic reconnection process by which thermal energy is generated

If a closed rectangle as shown in Figure 6 is taken, then the line integral $\boldsymbol{B.dl}$ has the value B_y. $4l$ so that applying Stoke's theorem,

$$\iint \boldsymbol{j.dS} = \frac{1}{\mu}\iint(\nabla \times \boldsymbol{B}).\boldsymbol{dS}$$

$$= \frac{1}{\mu}\int \boldsymbol{B.dl} = \frac{1}{\mu}B_y 4L.$$

Again, $\iint \boldsymbol{j.ds} \cong j\,4\,Ll$.

Hence, $j\,4\,Ll = \frac{1}{\mu}B_y 4L$

or, $\quad j \cong \frac{B_y}{\mu l}$.

As l becomes smaller, j becomes as large as we please. By omitting the suffix in B_y, we can write B instead, $j \cong \frac{B}{\mu l}$.

As the width of current sheet is very small the sheet possesses much larger current densities so that the magnetic field may quickly slip through the homogeneous conducting medium.

5. Energy evolved for regulating the earth's dynamic processes

Most current sheets are likely to be rather transient in nature. Let us suppose that the faces of a current sheet have an area of a^2. Let the magnetic flux of strength B is carried across the faces into the sheet, where it is converted into heat in a continuous manner. If the field B originally occupies two cubes of side 'a' either side of the sheet, it contains magnetic energy of amount.

$$W = \frac{a^3 B^2}{\mu l}$$

which is released in the form of heat. This energy release is of the order of 10^{25} Joules which is sufficient for any kind of geodynamical processes to become effective.

If V be the speed with which magnetic flux is carried into the sheet, then the time of energy release is $t = a/V$.

For a steady conversion process, the width of the sheet is $= \eta/V$, where η is the magnetic diffusivity.

References

[1] F Press and R Siever *Earth* (San Francisco : W. H. Freeman) (1985)

[2] G C Brown and A E Mussett *The Inaccessible Earth* (London Allen and Unwin) p 235 (1981)

[3] R J O' Connell and W S Fyfe *Evolution of the Earth, Geodynamic Series*, Vol. 5 (American Geophysical Union) p 122 (1981)

[4] H P M Bott *The Interior of Earth* 2nd edn (London : Edward Arnold) p 403 (1982)

[5] Lingun Liu and W A Bassett *Elements, Oxides, Silicates High Pressure Phases with Implications for the Eath's Interior* (Oxford Oxford Univ Press) p 250 (1986)

[6] L Rybach *Pure Appl. Geophys* **114** 309 (1976)

[7] L Rybach *Determination of heat production rate, Handbook of Terrestrial Heat Flow Density Determination* (eds) R Haenel, L Rybach and L Stegena (Dordrecht . Kluwer Academic) p 486 (1988)

[8] S T Tassos in *Proc. Int Symp on "New concepts in Global Tectonics"* (Tsukuba, Japan) (1998)

[9] T K Das and D Roy in *The Proc Technical Workshop for APT & APSG, 1996* (Kashima Space Research Centre, Japan) p 232 (1996)

[10] T K Das and D Roy in *The Proc. Int Symp. on "New concepts in Global Tectonics"* (Tottori University, Tsukuba, Japan) p 76 (1998)

[11] T K Das and D Roy in *Abstracts of XXVIth General Assembly of URSI* (Toronto University, Canada) **No. E6P 12 p** 301 (1999)

[12] D Roy and T K Das in *31st Int. Geo. Cong.* (Riode Janeiro, Brazil) (2000)

[13] R E Sheridan *Techtonophysics* **143** 59 (1987)

[14] S Chandrasekhar *Hydrodynamic and Hydromagnetic Stability* (Oxford Clarendon) (1961)

[15] L Bierman *Vierteljahrschr Astr. Ges.* **76** 194 (1941)

[16] P A Sweet *IAU Symposium* No. **6** p 123 (1958)

[17] T Gold and F Hoyle *Mon. Not. Roy. Astron. Soc.* **120** 89 (1960)